The NGST Science Instrument Capabilities

A Recommendation from the NGST Ad Hoc Science Working Group
To the NGST Project Scientists

December 29, 1999

Executive Summary

The NGST Ad Hoc Science Working Group recommends a core scientific instrument complement of three instruments for NGST: a wide-field NIR camera, a multiplexing NIR spectrograph, and a combined 5-28 µm camera spectrograph. These instruments are required to accomplish most but not all of the NGST core science goals defined by the highest ranked Design Reference Mission programs. No two-instrument complement can accomplish a satisfactory set of these goals. In addition, the NGST ASWG recommends that one of three additional instruments be provided based upon available funding and the interests of the international partners: a high resolution visible-NIR camera that fully samples the NGST point spread function; a high angular and spectral resolution NIR integral field spectrograph; or a high spectral resolution MIR integral field spectrograph.

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1.0 Introduction

The Next Generation Space Telescope is a major mission in the NASA theme: the Astronomical Search for Origins and Planetary Systems. The mission's central goal is the study of the earliest stars and galaxies and their evolution to structures such as the Milky Way. To accomplish these goals, as well as enable a broad range of astronomical studies, the NGST architecture utilizes a large (8 m dia.) space telescope to be deployed at L2, behind a large sunshade. There, the telescope and the science instruments will radiatively cool to 30-50K. At these temperatures, the stray infrared emission from the telescope is less than the zodiacal light background for $\lambda < 10$ µm. At longer wavelengths, the NGST capabilities will remain unique compared to other missions and facilities because of its large size compared to that of SIRTF and ISO and a background 4-5 orders of magnitude lower than that of ground-based telescopes.

The NGST mission is a collaboration among NASA, the European Space Agency, and the Canadian Space Agency. Each agency contributes to the technical and scientific success of the mission, including the scientific instrumentation. During 1998-99, twelve international teams considered the scientific and technical aspects of visible, near-infrared (NIR), and mid-infrared (MIR) instruments for NGST. In preparation for the apportionment of scientific and development responsibilities among the three agencies, John Mather, the NGST NASA Project Scientist charged the NGST Ad Hoc Science Working Group (ASWG) and an independent Technical Review Panel to assess the scientific priorities and technical readiness of these and more general scientific instruments. This report describes the process and scientific recommendations by the ASWG. It makes frequent reference to the work of the Technical Review Panel. Their report and more information on the NGST mission may be found on the NASA NGST web site, **http://www.ngst.nasa.gov/**. This and other references are provided in Appendix B.

2.0 The ASWG Charge

In September 1999, the ASWG received the following charge and instructions from John Mather.

"As part of the apportionment of the instrumentation responsibilities among the U.S. and the international partners for NGST in spring 2000, the NASA NGST Project Scientist has charged the Ad Hoc Science Working group to recommend the desired instrument complement, based upon its scientific value. A Technical Review Panel has been separately charged to evaluate the technical feasibility and cost estimates of potential instruments. The ASWG and Technical Review Panel will have access to the following documents:

- Presentations and posters at the NGST Science and Technology Exposition, 13-15 Sept.
- The Huchra Committee report on generic NIR spectrograph concepts
- The reports of the international ISIM Study teams. (U.S. due 1 Sept., ESA, CSA due 1 Oct.)
- Various technical reports such as the Detector Working Group report and the NGST Design Reference Mission programs and prioritization -- available from the web
- Initial instrument complements (3 & 4 instruments) defined by the ASWG on 16 Sept.

"The ASWG will meet on 3-5 Nov. 1999 and 22-23 Nov.1999 to prepare its recommendation. The elements of that recommendation will be:

- "Which of the various instrument concepts can best carry out each portion of the Design Reference Mission for NGST?
- "What are the strengths and weaknesses of the various concepts for carrying out the science described in the DRM?
- "Are there important discriminators among the instrument concepts in terms of expected overall sensitivity, complexity, or flexibility in enabling the broad range of science expected to be relevant in the NGST time frame, even if not necessarily contained in the DRM?
- "Considering the overall NGST science mission, what is the optimum complement of 3 instruments for accomplishing those objectives? What are the strengths of that complement, the weaknesses?

- "Considering the overall NGST science mission, what is the optimum complement of 4 instruments for accomplishing those objectives? What are the strengths of that complement, the weaknesses?"

In addition, John Mather also chartered three subcommittees to assist the larger group in reaching its recommendation. These were delineated along instrumental capabilities:

a) Visible & NIR Cameras (0.5 um - 5 um, including coronagraphic, tunable filter and Fourier transform capabilities. These capabilities can be considered to focus on angular resolution limited primarily by the diffraction (the size of the primary mirror) and low spectral resolution, $\lambda/d\lambda = R <= 100$.)

b) Multiplexing NIR spectrographs (including imaging Fourier transform spectrometers (IFTS), integral field and multi-object spectrographs, R = 100-10000)

c) MIR cameras and spectrographs ($\lambda > 5$ um)

These subcommittees were to brief the ASWG at the first meeting, Nov. 3-5, and prepare technical reports consisting of the following information.

"Introduction: members of the committee, meeting dates;
Key Scientific Capabilities/Parameters for NGST tied to DRM;
Generic Instrument Concepts mapped to ISIM Studies;
Review of ISIM Studies (key features): pros and cons per study;
Overall ranking/importance of concepts with regard to various
instrument complements;
Summary findings and recommendations"

The members of the ASWG subcommittees and the attendees of the November meetings referenced above are listed in Appendix A.

3.0 Reaching Consensus

November 3-5, 1999 Space Telescope Science Institute

The ASWG met at the Space Telescope Science Institute on Nov. 3-5 1999 and again at the Belmont Conference Center in Elkridge, MD on Nov. 22-23 1999. At the first meeting, the ASWG received the reports of the Technical Review Panel and the three ASWG subcommittees. During these reports, the ASWG included representatives of the instrument studies (see Appendix A). Questions of both the Technical Review Panel and the three subcommittees were posed by all present. There were three areas that received the majority of the attention.

- Technical Readiness: The Technical Review Panel identified the Micro-Electro-Machining Systems (MEMS) technologies as being the most immature and financially risky of the various technologies being considered.
- Relative Costs: The Technical Review Panel used parametric analyses to estimate the relative costs of the various instruments. In relative terms, the 4-channel camera and the FTS imager were of comparable cost while the spectrographs had slightly lower costs. Because the parametric costs analyses could not provide absolute cost estimates, the ASWG would be required to adopt one of several "grass roots" costing exercises to bound its instrument complements.
- NIR Dispersive Spectrographs and Imaging Fourier Transform Spectrometers as alternate methods for providing the NIR spectroscopic capability required by the DRM: The capabilities of dispersive spectrometers and IFTS are significantly different. The former offer the highest possible sensitivity for single sources while an IFTS can provide the most effective means for obtaining a spectrum for every pixel in a large field of view. Representatives of one of the IFTS studies presented their view of how the IFTS would be used on NGST.

The three ASWG subcommittees presented a list of desired scientific capabilities and instrumental techniques drawn from their deliberations. These were presented to all attendees for comment and embraced essentially all the studies. Here "barebones" reflects the minimum configuration recommended by the respective ASWG subcommittee.

ASWG Subcommittee Recommended Science Capabilities
(Not in order)

2'x2' NIR camera (barebones)
4'x4' NIR camera FOV extension
Adding IFTS capabilities to NIR/MIR camera
Dedicated NIR coronagraph
Dedicated visible camera (0.6-1+ micron, Nyquist sampled at 1 µm)
NIR R = 100 spectroscopy with highest possible point source sensitivity
NIR R=1000 MOS or integral field spectrograph
NIR, R =3-5000 spectroscopy, with high angular resolution over a small integral FOV
MIR imager (2'x2') (barebones)
MIR spectrograph R=1500 (barebones)
MIR, R=3-5000 spectroscopy, with high angular resolution over a small integral FOV

After further discussions of each of these options and attaching a relative cost to each item based on Technical Review Panel estimates, the ASWG minus the study representatives (the "ASWG-minus") voted on the priorities of the eleven capabilities. The order of that vote was:

Top Six Ordered Capabilities

2'x2' NIR camera (barebones)
NIR R=1000 MOS or integral field spectrograph
MIR imager (2'x2') (barebones)
NIR R = 100 spectroscopy with highest possible point source sensitivity
MIR spectrograph R=1500 (barebones)
4'x4' FOV extension to NIR camera

Extended Capabilities (not in priority order)

Adding IFTS capabilities to NIR/MIR camera
Dedicated NIR coronagraph
Dedicated visible camera (0.6-1 µm, Nyquist sampled at 1 µm)
NIR, R =3-5000 spectroscopy, with high angular resolution over a small integral FOV
MIR, R=3-5000 spectroscopy with high angular resolution over a small integral FOV

The total estimated cost of the top six capabilities appeared consistent with the budget for the science instrument payload and its supporting systems ($225M FY96) including contingency and fee). The voting for the top six capabilities showed a strong consensus of the ASWG-minus along the following lines:

1. The NIR camera is the central, most important instrument on NGST and must be as sensitive as possible to detect and characterize "first light" and the formation and evolution of galaxies. However, it is an expensive instrument and, if simultaneous guiding were not considered, the full field of view could be sacrificed to enable other critical capabilities.

2. The R=1000 multiplexed spectrograph is crucial for the study and characterization of high redshift galaxies. It provides emission-line diagnostics that address star-formation rates, metallicities, and physical association (through 100 km/s kinematics). A wide FOV is important because Milky Way progenitors would subtend arcminute regions on the sky at all redshifts.

3. The MIR camera provides a more sensitive and much higher resolution view of the universe than SIRTF. It will detect the established stellar populations in high redshift galaxies and study the dust-covered regions of star formation at high redshift, protostars, debris disks, etc. It extends the wavelength coverage of NGST by 2.5 octaves (from 3 to 5.5 octaves).

4. An extremely sensitive R=100 NIR spectrograph is mandatory to confirm the photometric redshift surveys and to characterize the faintest sources detected by NGST, be they z~20 galaxies or halo brown dwarfs.

5. The R~1500 MIR spectrograph is required to detect the diagnostic lines of high redshift galaxies ($z > 7$), probe z~5 luminous MIR/FIR infrared sources, and study the physics of star formation and circumstellar disks in our galaxy and its neighbors.

6. Extending the field of the NIR camera is crucial for detecting rare or faint signals such as high redshift supernovae, weak gravitational lensing by z~1-3 field galaxies and dark matter, and the low mass stellar populations in nearby, extended star formation regions.

November 22-23, 1999 Belmont Conference Center

Technical Briefings

At Belmont, Nov. 22-23, the ASWG-minus received briefings by the chair of the Technical Review Panel and other technical briefings related to the science capabilities listed above. In summary, these reports indicated:

- MEMS devices such as the micro-mirror and micro-shutter arrays require many years to develop and are often constrained by the capabilities of the development houses/labs. At this point, the three micro-mirror/shutter technology development projects underway for NGST appear feasible, but each has unique development challenges. It is not yet possible to predict which technology development will succeed or falter.
- Negligible diffraction losses are expected in the Yardstick MOS illustrating that a MOS instrument of this type is feasible relative to the ISIM volume allocation.
- The Technical Review Panel identified cryocoolers as preferable to cryostats for meeting MIR detector cooling requirements because of the weight and integration/test issues. However, cryocoolers are another area requiring significant technology development before the implementation phase.
- Both HgCdTe and InSb can be used at visible wavelengths ($\lambda < 0.6$ µm) with the appropriate anti-reflection coatings and, for HgCdTe, removal of substrate material. The modulation transfer functions (MTF) appear satisfactory for NIR imaging but may be worse at visible wavelengths because the photons are absorbed closer to the surface, in regions of lower, pixel-defining fields.
- Visible and NIR filters can be provided that remove 99% of long wavelength light and have a 90% transmission in the desired bandpass. Filters with reductions of 99.9% with an 85% transmission are also straightforward. This level of reduction appears satisfactory for the photometric redshift programs but would not be sufficient for deep visual photometry of faint stars in old, dense stellar clusters.
- If the NIR camera is not used as the telescope fine guidance sensor, the cost of adding a suitably robust alternate guiding system would be $30-80M or equivalent to the cost of an additional science instrument.
- The cost of increasing the field of view of the NIR camera from 2' x 2' to 4' x 4' is approximately 90% the cost of the 2' x 2' camera based upon parametric formulae.
- Assuming that the NGST primary is diffraction-limited at 2 µm, we expect that the PSF at 0.6 and 1.0 µm should be narrower and sharper than at 2.0 µm. The encircled energy at 0.6 µm will depend on the amount of mid-frequency scatter (wavefront errors on scales of fractions of a mirror petal).

Multiplexing Trade Studies

NGST enjoys several advantages over ground-based telescopes for NIR spectroscopy. The most obvious is the lack of strong OH emission lines and atmospheric absorption. A second potential advantage is a stable, diffraction-limited PSF over a relatively large field (>4'x4'). To take advantage of these advantages, the NGST requires an instrument capable of obtaining many spectra from many targets simultaneously. The ASWG-minus discussed the multiplexing capabilities of three qualitatively different instrument designs in the context of the DRM and, in particular, the DRM 7 which requires R ~ 1000 spectra from thousands of high redshift galaxies. These discussions revisited the conclusions of the NIR Spectrograph Subcommittee and the Huchra subcommittee. Following these discussions, the ASWG-minus ranked the three spectroscopic concepts under the important assumption that each was technically and financially feasible. The rankings were:

NIR Multiplexing Spectrograph

Multi-Object Spectrograph (MOS, N ~ 1000, > 3' x 3' FOV)
Integral Field Spectrograph (IFS, 0.2" pixels, 25"x 25" FOV)
Imaging Fourier Transform Spectrograph (IFTS, > 4' x 4' FOV)

The primary drivers for this ranking were (in no order):

- The number of measurable high redshift galaxies per square arcminute, ~ 200. Much higher densities favor the IFS and IFTS, which potentially can measure 10,000-1,000,000 objects simultaneously and can efficiently measure compact scenes such as merging galaxies and dense star clusters.
- The astrophysically interesting angular scales, arcminutes for proto-galaxies and clusters of galaxies. These scales favor the large FOV MOS and IFTS.
- The higher sensitivity of dispersive spectrographs (MOS and IFS) over Fourier transform spectrometers that require a number of images comparable to the resolution and can therefore take 1-2 orders of magnitude longer than a dispersive spectrograph to achieve a comparably deep spectrum. As detector performance improves, the relative advantage of dispersive spectrographs increases.

The latter argument was debated at length. Several scientists argued that the IFTS could provide a set of deep data cubes that could be as great a gold mine for astronomy as the Hubble Deep Field (HDF) could. There was also consideration of a dispersed IFTS that would combine some of the wide field advantages of the IFTS with single target sensitivities comparable to a dispersive spectrograph, even for R~1000. However, the dispersed-IFTS concept was not sufficiently developed to consider on the same footing as the other technologies. In the end, the MOS was seen as embodying the combination of wide field and high sensitivity needed to accomplish the NGST science goals as described in the DRM and developed further by the two spectrograph subcommittees.

Since the most capable MOS requires MEMS technology to be successfully developed in the next three years, the ASWG-minus considered whether the IFS, IFTS, and mechanical MOS technologies would be acceptable alternatives in the event that the MEMS technology does not reach the desired readiness level in this short time. For this purpose, the ASWG-minus considered the image slicing IFS and a mechanically implemented MOS (>100 movable slits or fibers) as being equally acceptable offramps, with the former being a relatively mature technology. The low-sensitivity of the IFTS and the need to fund significant technology development to bring it to readiness counted against the traditional, "non-dispersive" IFTS.

Developing the Instrument Complement

Following the prioritization of the multiplexed R~1000 NIR spectrograph, the ASWG-minus revisited the list of key scientific capabilities developed by the ASWG-minus subcommittees and initially ranked on Nov. 5. Each was carefully defined in terms of estimated cost and capabilities. The list was reranked with each member providing a ranked list, 1-11. The order was essentially unchanged from the result described earlier with the exception of the 4'x4' NIR camera, which was ranked second below the 2'x2' camera. This result reflected the ASWG's understanding that the NIR camera could provide guiding information for the fast-steering mirror (FSM) and that no dedicated guider would be required if the NIR camera had a 4'x4' FOV.

With these rankings, the instrument complement was straightforward to define. The first three instruments would be a 4'x4' NIR camera, an R~1000 NIR MOS, and a barebones MIR Camera-spectrograph using a common focal plane assembly. This instrument complement would provide the top six ranked capabilities with an estimated cost within the $225M target. However, some of the core DRM scientific objectives would not be met with these three instruments. After further discussion, the ASWG-minus reduced the options for a fourth instruments to: a high angular resolution camera to take advantage of the NGST PSF at wavelengths $\lambda < 2$ microns; a high angular and spectral resolution (R=3000-5000) IFS for the study of kinematics in compact regions such as AGN and galactic nuclei; and MIR IFS with spectral resolution R~3000 for the study of stellar velocity dispersions seen in CO for $z > 2$ galaxies, gas phase physics in the ISM and the emission from debris disks and the circumstellar regions around protostars.

The ASWG-minus was asked to vote for one of the three additional instruments. The vote was essentially split evenly among the three (6,7,7). The ASWG-minus concluded that the scientific case was equally strong for any of the three additional instruments. It recommended that the allocation process consider adding one of these options as a fourth instrument depending on the expertise and interests of the international partners but not if the addition compromised the performance of any of the three core instruments.

4.0 The Recommended Instrument Complement

The following summarizes the recommendation for the three core instruments and includes many of the key science programs that are enabled by each instrument.

Visible/NIR Camera

This camera will have NIR and visible filters and be sensitive over the 0.6 - 5 μm wavelength range, with a 4′x4′ field of view (FOV), and 0.03" pixels ($\lambda/2D$ at 2.4 μm) requiring an $8k^2$ array detector. A basic spectroscopic capability with $R=\lambda/\delta\lambda=100$ is essential and will be provided either in this camera (e.g., with a slit and grism) or in the spectrograph described below. Sub-arrays within this camera could possibly serve as a guide star and wavefront sensor. A low-cost coronagraphic capability could also be provided.
This camera is required for most of the mission's highest-ranked science programs, including the detection of light from the first stars, star-clusters or galaxy cores, the study of high-redshift galaxies seen in the process of formation, investigation of dark matter through studies of weak gravitational lensing, the discovery of high-redshift supernovae, and studies of the stellar populations in nearby galaxies, young stellar objects in our own Galaxy, and Kuiper Belt Objects in our Solar System.

NIR Multi-object Dispersive Spectrograph

A multi-object dispersive spectrograph will have a wavelength range of 1 – 5 μm, with R~1000, pixels matched to the sizes of high-redshift galaxies (~0.1"), a 3′x3′ or larger field of view, and will be capable of observing >100 objects simultaneously. Ideally, the spectral resolution will be selectable and will extend down to R~100, unless this capability is provided in the Visible/NIR camera. The preferred technology for this instrument is the micro-electro-mechanical systems (MEMS) selectable micro-mirrors or micro-shutters. In the event that this technology were unavailable, a multi-object spectrograph (MOS) with mechanically positioned slits (either with jaws or optical fibers) or a wide-field integral field spectrograph (IFS) would be acceptable alternatives at reduced observing efficiency.

The key scientific objectives of this instrument are studies of star formation and chemical abundances of young galaxies at high redshifts, measurement of the hierarchical development of large-scale structure at high redshifts, and the study of the initial mass function in young stellar clusters.

MIR Camera-spectrograph

This combined camera/slit spectrograph will be sensitive over the 5 – 28 μm wavelength range with R=1500 and a 2′x2′ field sharing a single focal plane array. A low-cost coronagraphic capability could be provided.

The scientific objectives for this instrument include the study of old, established, stellar populations at high redshift, mid-IR (MIR) diagnostic emission line features of obscured star-bursts and AGN at $z<5$, Hα emission to $z\sim15$, local group AGB stars, the cool stellar mass function, the physics of protostars, circumstellar disk mineralogy, the sizes of Kuiper Belt Objects, and faint comets. This instrument will be ideal for the detailed follow-up study of new mid-infrared sources that will be discovered by the Space Infrared Telescope Facility (SIRTF) and Infrared Space Observatory (ISO).

The ASWG-minus recommends that one of the following three additional instruments be added to the core instrument complement.

NIR Integral Field Spectrograph

A integral field spectrograph (IFS) will be sensitive to NIR wavelengths, probably using an image slicer, and will be able to exploit the full spatial resolution of the NGST at spectral resolutions up to R~5000 in order to resolve the kinematics of small galaxies. This instrument will cover a contiguous field of 2"x 2" with <0.1" pixels. Key scientific objectives include measuring the masses of young galaxies at high redshift, the study of galactic nuclei and AGN at high resolution, and investigations of dense stellar clusters.

High Resolution Camera

A high-resolution camera will be optimized for a wavelength range of 0.6-1 μm and capable of sampling the full spatial resolution of NGST at short wavelengths. This instrument will have 0.01" pixels (λ/2D at 0.8 μm) and cover a minimum 1′x1′ field (2'x2' would be preferred). Key scientific objectives include studies of the morphology of high-redshift galaxies, the study of stellar populations in nearby galaxies, the determination of the ages of globular clusters through observations of white dwarfs, and the study of circumstellar disks.

MIR Dispersed Integral Field Spectrograph

An integral field spectrograph (IFS) will be sensitive to MIR wavelengths 5 - 28 μm, with R=3000-5000, high angular resolution (~0.3" FHWM at 10μm) sampling of a contiguous (2"x2") field. These spectral resolutions are required for measuring the masses of z > 1 early spheroids using the photospheric, CO 2.3 μm absorption bands; for studying gas-phase physics and chemistry in circumstellar disks, early protostars and comets; and for constraining the gas-dispersal and Jovian-planet formation time-scales in disks." If selected, this instrument could provide the R=1500 capability of the combined MIR camera/spectrograph included in the three instrument complement.

Appendix A: ASWG Participants

ASWG members	Nat.	Instrument Study	Nov. 3-5	Nov. 22-23	ASWG Subcomm.
Santiago Arribas	Eur.		√	√	
Jill Bechtold	US	Payload	√		
David Crampton	Can.	NIR spec.	√		
Ewine van Dishoeck	Eur.		√	√	MIR Cam/Sp.
Mike Fall	US			√	NIR Spec.
Robert Fosbury	Eur.		√	√	NIR Spec.
Jon Gardner	US		√	√	NIR Spec.
James Graham	US	IFTS	√		MIR Cam/Sp.
Tom Green	US	Payload			MIR Cam/Sp.
Matt Greenhouse	US		√	√	MIR Cam/Sp.
Don Hall	US		√	√	NIR Spec.
Paul Hicksen	Can.	Vis Camera	√		
John Hutchings	Can.		√	√	
Peter Jakobsen (ESA PS)	Eur.		√	√	NIR Spec.
Robert Kirshner	US		√	√	NIR Spec.
Olivier LeFevre	Eur.	NIR Spec.	√		NIR Camera
Simon Lilly (CSA PS)	Can.		√	√	NIR Spec.
Avi Loeb	US				
John MacKenty	US	NIR Spec.	√		MIR Cam/Sp.
Bruce Margon	US			√	NIR Camera
John Mather (Co-Chair, NASA PS)	US		√		
Mark McCaughrean	Eur.		√	√	NIR Camera
Mike Meyer	US			√	MIR Cam/Sp.
Simon Morris	Can.	IFTS	√		NIR Spec.
Harvey Moseley	US	NIR Spec.	√		MIR Cam/Sp.
Phil Nicholson	US			√	NIR Camera
Takashi Onaka	Japan		√	√	MIR Cam/Sp.
Michael Rich	US		√	√	NIR Camera
Marcia Rieke	US		√	√	NIR Spec.
Peter Schneider	Eur.			√	NIR Camera
Gene Serabyn	US	MIR	√		
Massimo Stiavelli	US		√	√	NIR Camera
Peter Stockman (Co-Chair)	US		√	√	MIR Cam/Sp.
John Trauger	US	Coronagraph			NIR Camera
Martin Ward	Eur.	Vis Camera			
Gillian Wright.	Eur.	MIR Camera	√		NIR Camera

Presenters & Observers	Affil.	Instrument Study	Nov. 3-5	Nov. 22-23	ASWG Subcomm.
Russ Alexander	CSA		√		
Pierre Bely	STScI		√		
Chuck Bennett	ITT	IFTS	√		
Richard Burg	NASA		√	√	
Scott Collins	UC Davis			√	
Jim Crocker	Ball		√		
Dennis Ebbets	Ball		√		
Harry Ferguson	STScI		√	√	NIR Spec.
Paul Geithner (Tech. Pan. Chair)	NASA		√	√	
David Hunter	STScI		√		
Larry Lesyna	L-M		√		
Knox Long (secretary)	STScI		√	√	NIR Camera
Pat McCray (historian)	GWU			√	
Craig McCreight	NASA				MIR Cam/Sp.
Mike Menzel	L-M		√		
Jon Morse	U. CO	NIR Camera	√		
Mike Regan	STScI		√		
Bernie Ruascher	STScI		√		
Shobita Satyapal	STScI		√		
Ethan Schreier	STScI		√	√	
Bernie Seery (Proj. Manager)	NASA		√		
Eric Smith (secretary)	NASA		√	√	NIR Camera
Guy Stringfellow	NASA			√	
Bob Woodruff	Ball		√		

Appendix B: References

NASA NGST Web site: http://www.ngst.nasa.gov

NGST Technical Review Panel Report:
http://ngst.gsfc.nasa.gov/cgi-bin/pubdownload?Id=569

ESA NGST Web site & Instrument study reports:
http://astro.estec.esa.nl/NGST/

HST & Beyond (Dressler) Committee report:
http://ngst.gsfc.nasa.gov/project/bin/HST_Beyond.PDF

The NGST Design Reference Mission
http://www.ngst.nasa.gov/science/drm.html.

The US , CSA, and ESA, instrument study reports maybe found at
http://www.ngst.nasa.gov/science/isimpage.html.

The Independent NIR Spectrometer Committee (Huchra) Report
http://www.ngst.stsci.edu/nir_spec_study99/nir_summary.html.

ASWG Meetings and Minutes: http://www.ngst.stsci.edu/ASWG.html

Project Scientists Instrument Complement Recommendation:
http://ngst.gsfc.nasa.gov/cgi-bin/pubdownload?Id=549